ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 7
Issue 3/2007

17 – 20

3/3

Registration of Crystallization Process of Ultra-Lightweight Mg-Li Alloys with Use of ATND Method

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Received on: 20.04.2007; Approved for printing on: 27.04.2007

Abstract

Magnesium alloys are characterized by advantageous ratio of strength and/or elastic modulus to density, that is, can sustain static and dynamic loads similar to iron and aluminium, and additionally feature good vibration damping. Castings from magnesium alloys are lighter with about 20 – 30% than aluminium alloys and with 50 – 75% than iron alloys, that is why they are used in aviation and rocket industry and everywhere the weight of a product is of important significance for conditions of its operation. Also automotive industry introduces to vehicle’s structure an elements (castings) manufactured from such alloys. On metallic matrix of magnesium alloys with lithium are also manufactured a composites reinforced with e.g. ceramic fiber, which are used as lightweight and resistant structure materials.
The paper presents an attempt of implementation of ATND method (Thermal-Voltage-Derivative Analysis) to monitoring of crystallization process of ultra-lightweight Mg-Li alloys. Investigated magnesium alloys with contents of about 2,3% Li, 10% Li and 11 % Li were produced in the Foundry Research Institute. Registration of melting and crystallization processes was made with use of the ATND method. Results of preliminary tests are shown in graphical form.

Keywords: Crystallization, Modification, Ultra-Lightweight alloys, ATD, ATND

1. Introduction

Magnesium belongs to the most lightweight metals (among stable metals in normal conditions). Due to its properties, low density – 1,8 [g/cm^3] namely, is lighter with 35% than aluminum, 73% lighter than zinc, 75% lighter than steel and 80% lighter than copper. It features good vibration damping capability and high durability (also in higher temperatures). It is estimated that about 1,9 mass% of Earth's crust consists of magnesium, and the oceans contain 0,13 mass% magnesium [1].

Recently, limited fossil fuel and environmental problems have promoted lightening of automobiles for the reduction of fuel consumption (it is known not from today that each reduction of vehicle mass with 100 kg results in fuel savings of up to 0,4 liter for each 100 [km] of driving) and construction of recycling system from various scraps. Consequently magnesium alloys are attracting great attention as lightweight materials that can be easily recycled [1], thus represents an excellent alternative in lightweight constructions. Depending of the specific functions, lightweight constructions have to be adapted to different criteria like producibility, ductility, energy absorbability and corrosion or combinations of them [2].

Magnesium alloys enjoy great success in armaments industry (components of helicopters, elements of armament and special equipment for troops), textile industry (seats of weaving looms and high-speed components like: spools, bobbins, brush-holders and others), are implemented by producers of audiovisual electronics (frames of loudspeakers, housings of cameras), medical accessories (components of x-ray apparatus) and sports equipment (structural elements of bicycles, elements of mountaineer's equipment, and structural components of rollers, etc.).

Low specific gravity is the main advantage of magnesium alloys, and therefore the alloys are used in aviation and rocket industry, and everywhere specific gravity of produced components is of significant importance for conditions of their operation. Good corrosion resistance, being equal to or even exceeding aluminum, is an additional advantage of the magnesium alloys. Magnesium alloys with aluminum, zinc and manganese have big technical importance, where Al and Zn increase strength of the alloys, whereas manganese increases anticorrosion resistance. Additional alloying additions improving their resistance for increased temperatures and improving their plastic properties and resistance for oxidation are: beryllium, calcium, cerium, cadmium and titanium, whereas iron, silicone and nickel reduce their resistance for corrosion.

Magnesium alloy components are usually produced by various casting processes. The most applicable methods are high-pressure die casting and gravity casting, particularly sand and permanent mould casting. Other relevant production technologies are: Squeeze Casting, Thixocasting and Thixomolding [3]

The Mg-Li alloys are the ultra lightweight constructional metallic materials having the 1.35-1.65 g/cm^{-3} density, that 1.5-2.0 times less than that of aluminum alloys. These density meanings are similar to constructional plastic density. The second principal advantage of the Mg-Li alloys is the fact that they have high ductility. It is caused by the isotropic body-centered cubic (bcc) lattice of them instead of hardly deformed at ambient temperatures and anisotropy hexagonal close-packed (hcp) lattice of traditional magnesium alloys [4].

The Mg-Li alloys are present in a few forms. In range of Li concentrations of up to 4%wt. –as hexagonal α phase with A3 (*hc*p) lattice, and in range of above 12%wt. Li – as β phase with regular A2 (*bc*c) lattice. Mechanical properties of the α phase are worse than β phase, which features very good machinability and weldability [5]. Alloys with Li content from 4 to 12%wt. occur in form of diphase ones and are present as solution of $\alpha+\beta$ phases. Alloying additives, e.g. 3 to 5% of Al, slightly increasing density, improve mechanical properties.

In the recent years an enormous growth of interest in magnesium and lithium alloys with Al, Cd, Zn and Ag alloying additives can be observed. Solubility of lithium in magnesium with hexagonal structure is low and amounts to about 5%wt., whereas magnesium forms a wide range of β solid solution, dissolving in lithium with regular structure, spatially centered up to 90%wt. (Fig. 1)

The lithium impacts advantageously on formability of magnesium alloys through substitution of not easy deformable hexagonal lattice by regular lattice, simultaneously causing reduction of mechanical properties due to emerging of β phase. Optimal combination of the properties is present in range of diphase $\alpha+\beta$ alloys with lithium content of above 10%wt. Alloys from such range of Li content in cast state have elongation of about 60%.

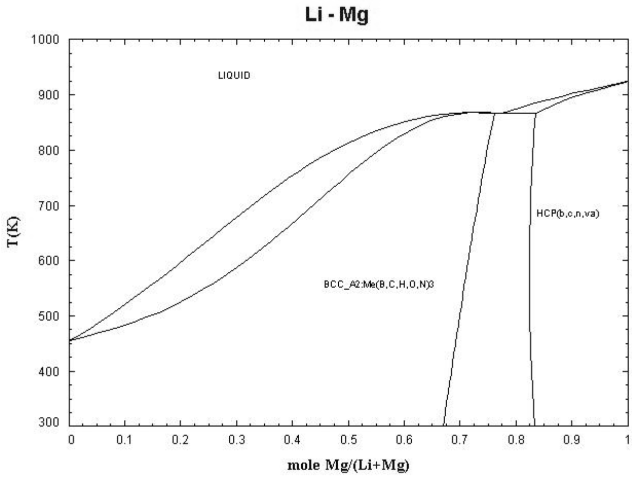

Fig. 1. Mg-Li phase system

Adding Al to Mg-Li alloys effects in occurrence of ductile λ phase (constituting solid solution of Al in Li and having regular spatially centered lattice) and hard, enabling precipitation hardening, inter-crystalline AlLi compound of η phase with B2 structure, within hexagonal structure of δ phase (constituting solid solution of Al in Mg with limited formability). Ductility of such alloys increases with growth of portion of $\delta+\lambda$ eutectic mixture. Sometimes, in the alloys is present unstable Li_2MgAl phase.

On metallic matrix of magnesium alloys with lithium are formed also a composites reinforced e.g. with ceramic fibers, which find more and more wide application as a lightweight, durable structural materials.

Obtaining the best material structure for specific requirements becomes possible with making use of theories on crystallization processes to control technological processes [6, 7]. Registration of a phenomena arisen in result of solidification process of alloys in order to determine their properties is enabled by a methods based on analysis of temperature changes run (thermal methods - ATD), of electric conductivity (electric methods - AED) and the method of the Thermal-Voltage Derivative Analysis (ATND).

2. Methodology of the research

ATND method consists in permanent measurement of temperature and electric voltage generated on probes during crystallization and phase transformations of solidified alloy. In course of the measurement there are measured generated voltage and temperature of tested piece. Run of the crystallization is shown in form of diagram created during solidification of the alloy [8, 9].

Tested alloys were produced from pure components and cast in experimental bench to melting and pouring of ultra-lightweight alloys in the Krakow Foundry Research Institute.

In the research were used Mg-Li alloys with the following contents of lithium:

- alloy no. 1 - 2,3 % Li,
- alloy no. 2 - 10 % Li,
- alloy no. 3 - 11 % Li.

Fig. 2 View of the testing stand

The testing stand (fig. 2) is composed of tubular silit furnace, two millivoltmeters and computer with software.

Melting and crystallization process took place in CO_2.protective atmosphere.

Suitably prepared specimens were put into the furnace's chamber, where melting and crystallization took place. In course of these processes has occurred permanent, simultaneous registration of changes of specimen temperature and difference of potential on measuring probes.

3. Description of achieved results of own research

The Fig. 3 shows course of heating (melting) and crystallization process of the alloy no. 1.

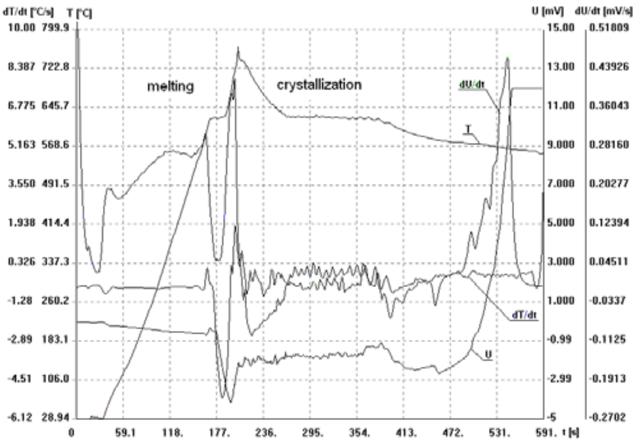

Fig. 3. Curves of ATND melting and crystallization of the alloy no. 1

The Fig. 4 shows course of heating (melting) and crystallization process of the alloy no 2.

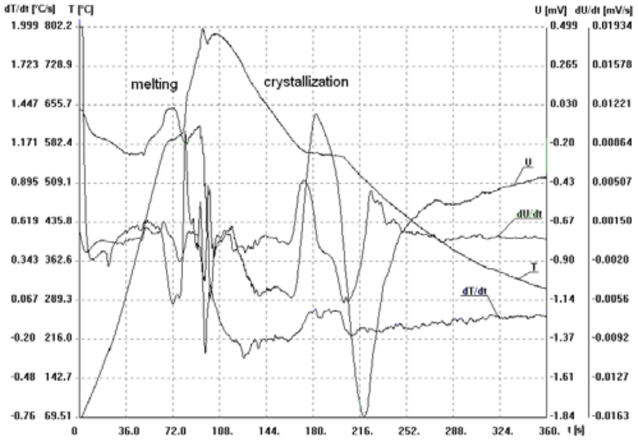

Fig. 4. Curves of ATND melting and crystallization of the alloy no. 2

The Fig. 5. shows course of heating (melting) and crystallization process of the alloy no 3.

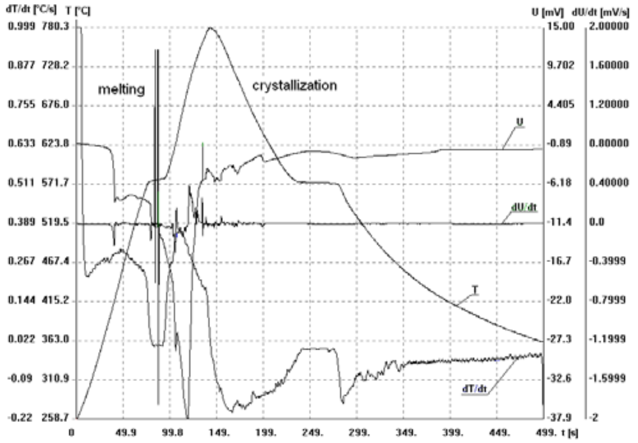

Fig. 5. Curves of ATND melting and crystallization of the alloy no. 3

4. Conclusions

Preliminary research has confirmed possibility of implementation of the Thermal-Voltage-Derivative Method (ATND) to registration of crystallization processes of ultra-lightweight Mg-Li alloys.

In the ATND method the thermal and voltage curves point at physical-chemical phenomena occurring during melting and crystallization of the alloy.

Temperature of investigated alloys is possible to be determined on base of obtained diagrams.

Acknowledgments

The research performed within framework of research project no. PBZ – KBN – 114/T 08/2004.

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